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Environmental Quality in Animal Production Housing Facilities: A Review and Evaluation of Alternative Ventilation Strategies

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ABSTRACT

Experts on animal production housing design were surveyed to determine current knowledge, identify potential control measures, and define research and development needs on indoor air quality in production animal facilities. Results indicated that for larger, more mature animals, properly designed and controlled natural ventilation systems are effective in providing good environments. For colder climates and more sensitive animals, a combined system with mechanical ventilation for cold weather and natural ventilation for warm weather works well. Experts noted that the high concentration of particulate matter is the most prevalent indoor air quality problem in animal housing facilities. They also noted that most problems with poor indoor air quality are due to poor design and management of existing technologies. To improve air quality in animal production housing facilities, better ventilation systems and air cleaners should be developed and utilized. Additionally, improving design and management of existing technology should be undertaken.

INTRODUCTION

The major contaminants in animal production buildings include dust, microbes, and gases of many types (ASHRAE 1993). The most prominent gaseous contaminants in production animal buildings include carbon dioxide (CO_2), ammonia (NH_3), methane (CH_4), hydrogen sulfide (H_2S), carbon monoxide (CO), odorous vapors, and other gases (Muehling 1970; McQuitty 1985). Particulate matter appears to be the major risk factor for animals and workers in animal buildings.

Research has indicated that respiratory problems are often observed in workers in production animal buildings. Complaints about respiratory problems are common in poultry and pig production (e.g., Clark et al. 1983; Hartung 1994). Studies also generally indicate potential for adverse effects on the health and performance of animals (e.g., Harry 1978; Carpenter et al. 1986a; Carpenter et al. 1986b; Donham et al. 1986; De Boer and Morrison 1988; Feddes et al. 1992). As a cause of death in pigs, respiratory tract diseases are the third most important, with the major causes being circulatory problems and diseases of the digestive system (Hellmers 1986).

Ventilation is the primary method used to control indoor air quality in animal buildings. The design and operation of ventilation systems depend largely on the purpose for which the animal is raised. For commercial production animals (e.g., swine, poultry), ventilation systems are designed to provide adequate airflow and supplemental heat to modulate temperature in winter and summer. For laboratory research animals (e.g., laboratory rodents, nonhuman primates), ventilation systems are designed to provide more precise control of environmental conditions because variations in environmental conditions affect research results.

The objectives of this research were to (1) conduct a detailed literature review of ventilation strategies that have been proposed for animal housing facilities and (2) describe and evaluate current ventilation strategies for each type of animal facility and identify the most promising strategies for improving indoor air quality. Identifying the most promising strategies for improving IAQ in animal housing facilities, considering source control, dilution, and air cleaning, will help engineers design better facilities. Of equal importance, a review and summary of strategies for achieving acceptable IAQ in animal facilities will provide information for engineers designing commercial, industrial, and other specialized environmental control systems.

This paper summarizes the expert survey results for production animal facilities. It reviews current knowledge, identifies potential indoor air quality (IAQ) control measures, and demonstrates that additional research is needed to develop effective IAQ control strategies. Results of the study for laboratory animal facilities have been presented by Maghirang et al. (1996).

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LITERATURE REVIEW OF INDOOR AIR QUALITY CONTROL STRATEGIES

A detailed literature review on ventilation and environmental air quality in animal facilities was conducted as part of ASHRAE RP-784. A database of published literature was developed (Riskowski et al. 1995) and included over 1400 articles. Articles were reviewed to determine potential control strategies for gaseous contaminants and particulate matter. A summary of the control strategies is presented below. A detailed discussion of the major contaminants in production animal facilities is presented in Riskowski et al. (1995).

Contaminants in ventilated spaces can be controlled using one or a combination of the following strategies: source control, ventilation control, and removal or air cleaning. Source control reduces contaminant concentration by directly reducing the contribution of sources. Ventilation control dilutes indoor air with outdoor air to reduce contaminant concentration. Air cleaning controls contaminant concentration by actively removing it from the indoor air through one of several physical or chemical methods.

Various control methods have been tested and proposed for production animal buildings. However, differences in measurement methods and conditions make it difficult to compare results and make valid conclusions about the effectiveness of the various control strategies.

Control Of Gaseous Contaminants

Gaseous contaminants are mainly products of animal metabolism and decomposition of fresh and stored manure (Muehling 1970; McQuitty 1985). Control of gaseous contaminants in production animal facilities has been limited primarily to ventilation (i.e., dilution) and source control. There are currently no widely used and economical methods for removing gaseous contaminants from animal buildings.

Source Control Strategies

Source control involves controlling manure to reduce the release rates of gases and odors from decomposing manure. The following strategies have proved to be effective or show promise in controlling gaseous contaminants.

Manure removal and pit ventilation. Removing manure from the building within three days removes the source before it decomposes sufficiently to release the most offensive gases. Intercepting gaseous contaminants and exhausting them from the building through manure pit ventilation has been helpful in reducing contaminant levels in the animal and worker breathing zones.

Control of air velocity over the manure surface. The release rates of ammonia and other gases from manure increases with increased air velocity across the manure surface. Increasing room air exchange rate from 2 to 4 air changes per hour increased the ammonia release rate from 250 mg/h to 350 mg/h per a 75 kg pig (Gustaffson 1987). Adjusting air diffusers to provide low air velocities across the manure surface can reduce gas release rates.

Treatment of liquid manure pits. Treatment of liquid manure pits can reduce gas release rates from manure pits (Heber 1993). Anaerobic conditions in the manure will reduce buildup of solids and toxic gases (Donham et al. 1985). However, anaerobic conditions are difficult to attain because the loading rates, solids content, ammonia content, buffering capacity, and temperature must be right. It is most feasible in swine farrowing buildings that have low loading rates. Adding water to the manure reduces ammonia concentrations by enhancing anaerobic conditions and diluting the concentration of urine (Kellems et al. 1979). Microbial activity can be reduced by lowering manure pH or adding chemicals. However, this also increases solids buildup and retards manure stabilization, which increase the potential of water pollution after land application.

NH_3 is water soluble and can remain in the water in the dissociated form as ammonium (NH_4^+). Only the portion that is present in the nonionized form can become volatile and be released as gas. The proportion of volatile ammonia in the total ammonia concentration depends on manure pH and temperature. The higher the pH, the more ammonia that is present in the volatile form (Heber 1993). The largest increase in ammonia release occurs between a pH of 7 and 10 at high temperatures. At a pH less than 7, only small quantities are released. If pH is below 4.5, negligible quantities of free ammonia are present. Manure pH can be lowered by adding nitric acid (Oosthoek et al. 1990).

Chelated copper-sulfate solutions are used to retard gas-producing bacteria. Other chemicals that are used include paraformaldehyde, superphosphate, phosphoric acid, acetic acid, and propionic acid. Crystalline hydrated aluminosilicates (zeolites) may be used to absorb ammonia in the manure (Carlile 1984).

Feed Additives

Three-phase feeding with the addition of synthetic amino acids has been shown to reduce ammonia emissions (Franz et al. 1989). Feed additives based on Yucca extracts are sometimes added to feed at low levels that tend to bind ammonia, reducing its levels by 1/3 to 1/2, thus, preventing its release (Switzky 1993).

Manure and feed additives for reducing NH_3 release have not yet been tested over long periods and their effectiveness is still debated. Feed additives appear to have a greater effect than manure additives (Heber 1993). Lack of standard test protocols makes it difficult to compare and evaluate effectiveness of these additives (Hartung and Phillips 1993).

Air Cleaning

Scrubbing. Current odor control techniques do not prevent malodorants from escaping to the surrounding air. However, several studies indicate the possibility to control the discharge of malodorants by washing or scrubbing them from the exhaust air. Van Geelen and Van der Hoek (1977) reported that scrubbers in a swine building ventilation system resulted in dust-free air and reduction of the odor intensity by 60% to 85%. Schirz (1977) also reported odor removal efficiencies

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ranging from 50% to 90%. Through studies of air filtration in a water spray system with baffle impingement filters, Wilson (1971) concluded that water combines with NH_3 and other malodorous gases and carries them away in solution. Van Geelen (1973) found that scrubbers similar to those in industry greatly reduced the odor level of air exhausted from swine buildings. The scrubber reduced concentration of ammonia from 80% to 99% and changed the pH from 8 to between 6.4 and 7.2.

Wet scrubbers are sometimes packed with special material to give extended surface contact between the polluted air and scrubbing liquid. The cross-flow, packed-bed wet scrubber developed by Licht and Miner (1979) removed 90% of particles >5 μm, 50% of particles >1μm, 25% of ammonia, 15% of carbon dioxide, and 50% of microorganisms in a swine building. Pearson (1989) developed and evaluated a wet scrubber with a packing material usually made up of pieces of polypropylene molded in shapes that presented a large surface area per unit volume but had a low resistance to airflow. The packing was kept thoroughly wetted by a water distributor above that was supplied with recirculated water pumped from the tank at the bottom, plus fresh water. Pearson reported that the scrubber removed 90% and 60% of dust and ammonia, respectively.

The above studies indicate the potential for wet scrubbers to remove odors from the animal building air. Research is needed to develop practical technology for scrubbers.

Biofiltration. Biofilters pass air through a medium designed to support large populations of desirable bacteria for breaking down odorous and other undesirable contaminants in the air of animal buildings. Biofilters are used primarily to reduce emissions of contaminants from exhaust air. Studies in Europe (Saether and Skjelhausen 1991; Schirz 1991; Scholtens and Demmers 1991) show the potential of biofiltration.

Control of Particulate Matter

Airborne dust particles originate from the feed, animals, feces, and litter, if it is used (Hartung 1994). Dust control strategies for production animal buildings have been discussed elsewhere (Maghirang et al. 1995). Engineering control strategies include reducing the rate of emission (source control), adequate and effective ventilation (ventilation control), and air cleaning (removal control). Source control strategies include use of feed additives (Chiba et al. 1985; Gore et al. 1986; Chiba et al. 1987; Heber and Martin 1988), cleaning dusty surfaces (Pedersen 1992), and spraying or sprinkling oil over surfaces (Takai et al. 1993; Zhang et al. 1994). Ventilation control includes purge ventilation (Robertson 1989) and effective room air distribution systems (Harry 1978; Van't Klooster et al. 1993). Air cleaners include air filters (Pritchard et al. 1981; Carpenter et al. 1986a, 1986b; Carpenter and Fryer 1990), electrostatic precipitators (Bundy 1984, 1991), and wet scrubbers (Licht and Miner 1979; Pearson 1989). Promising techniques involve feed additives, oil sprinkling, and effective room air distribution. Technical and economic constraints have prevented these methods from being widely practiced in production animal buildings. Effective and economically feasible dust control methods should be developed and systematically tested under controlled laboratory and field conditions.

SURVEY OF DESIGN EXPERTS—VENTILATION AND IAQ

A survey of experts was also conducted to determine the current state of knowledge on ventilation and IAQ. Forty experts in animal facility design were contacted by phone or written survey, and 25 responses were received. The survey was outlined to determine (1) the most common ventilation/environmental control systems for various types of animal facilities, (2) the effectiveness of current ventilation technology in controlling IAQ in animal buildings, (3) the most common IAQ problems in animal housing, (4) existing methods and strategies for controlling each of the IAQ problems and their effectiveness, and (5) new and emerging technologies that show promise for IAQ control.

Most respondents were directly involved in facility design and/or research and development for animal housing. A few were livestock producers, extension workers, or equipment manufacturers. All but the producers were experienced with the design of the environmental control systems, and most were also involved with the entire facility design. Many of the respondents were also involved with troubleshooting and evaluating existing ventilation systems. Almost all of them were involved in designing both mechanical and natural ventilation systems, and about half also designed a combination of mechanical and natural ventilation systems. All production stages of swine, dairy, poultry, beef, sheep, and horse facilities were represented.

Most Common Environmental Control Systems

Swine

Farrowing and nursery. Almost all farrowing and nursery buildings are mechanically ventilated (negative pressure) to achieve more precise control of thermal conditions. Relatively small rooms with individual ventilation systems are common. Manure storage or gutter ventilation is prevalent for the cold weather ventilation rate. Ventilation air into nurseries is often preheated in a hallway before distribution in the animal rooms to reduce thermal buoyancy effects and drafts on the animals. Additional heat is typically provided in rooms using unvented unit heaters. There are a few push-pull (neutral pressure) systems that are usually operated with tempering hallways, although they tend to be expensive.

The most common air diffuser is a continuous slot with adjustable baffle. Problems have been reported on manually adjustable systems due to a lack of understanding or concern of the operators. Poorly adjusted diffuser baffles can create drafts on the animals and/or constrict ventilation rate. Some experts recommend automatic baffle controls even though the initial cost is high. Counterweighted, self-adjusting intermittent (box) ceiling or wall diffusers are becoming popular. Some designers use ceiling intermittent or slot diffusers in winter to obtain attic heat and sidewall diffusers in summer for cooler outside air.

Many producers are using proportional or multi-stage integrated controllers instead of individual thermostats. Integrated controllers can control all the fans or natural vent openings as well as the heaters or coolers so they all operate in conjunction with each other and reduce temperature fluctuations.

Growing and finishing. For growing and finishing buildings, naturally ventilated, gable-roof buildings are the most common, although mechanically ventilated and heated buildings are also used in colder climates. Most of the naturally ventilated buildings have open ridges and large sidewall openings. Small winter diffusers are usually provided by opening the top of the large sidewall opening a small amount rather than providing separate eave openings in roof overhangs. Plain uncapped ridge openings are specified most often. Ridge caps have been shown to reduce airflow by around one-half, whereas upstands of only 2-6 in. (5-15 cm) have shown substantial increases of airflow from ridges. In colder climates, the ridge opening is often adjustable. Most openings are manually adjustable, but automatic adjustment is becoming popular. Naturally ventilated buildings usually do not have a ceiling, but many newer units have a ceiling to provide high insulation levels. With ceilings, ridge vents are provided by large square chimneys spaced at regular intervals or ceilings that follow the center truss webs up to a continuous ridge opening. One expert recommends large ridge openings (around 16 in. [40 cm]) to allow the building to cool down faster on calm, warm nights, while other experts do not prefer wide ridge vents.

The large sidewall openings of naturally ventilated buildings are usually closed down in cold weather with curtains. Insulated curtains may be used on the north wall in colder climates. Many curtain systems are automatically controlled. Sidewall vent doors are expensive and difficult to operate but can be well insulated. If vent doors are used, cracks around doors are sized to supply cold weather rate ventilation. Some supplemental heat may be needed for smaller pigs in these facilities. Many facilities may have water sprayers by the sidewall curtains to help cool the swine in hot weather. Some experts suggest that room size be limited to enhance ventilation and reduce the exposure of animals to disease. Limiting room size to 300 pigs per room has been recommended.

Many units use natural ventilation in warm weather to reduce costs and mechanical ventilation in cold weather to provide more precise control of thermal conditions during this critical period. Buildings with combined natural and mechanical ventilation systems usually provide cold weather ventilation rate with fans that draw air from manure storage or gutter and operate continuously to reduce odor levels in the building. These combination buildings often have ceilings with intermittent air diffusers to provide fresh air in cold weather. Others may have an inflatable recirculation duct with duct fan to distribute the incoming fresh air.

Mechanically ventilated tunnel systems are common in the Southeast and are becoming popular in the Midwest. With tunnel ventilation, all fans are located in or near one endwall and fresh air usually enters through the opposite endwall. In some cases, air is brought in through ceiling intermittent diffusers in cold weather and the opposite endwall in warm weather. In hot weather, the entering air often passes through an evaporative cooler. Some designers do not recommend tunnel ventilation because animals near the air diffuser may get excessive drafts while animals on the opposite end are exposed to contaminated and warm air.

Gestation and breeding. Many gestation and breeding buildings are naturally ventilated. However, due to reduced reproductive performance in hot weather, many are mechanically ventilated with tunnel systems. In the Midwest, some may be naturally ventilated most of the year but have mechanical tunnel ventilation systems with evaporative cooling for the hot days.

Poultry

Chicken. Most environmental control systems are mechanically tunnel ventilated or naturally ventilated with exhaust fans for minimum ventilation. Some use mechanical ventilation with sidewall fans and a baffled continuous slot diffuser along the top of both sidewalls. Fans pull air from the manure storage area for layers. These buildings are usually heated with unvented, gas-fired heaters, but radiant heaters are becoming popular. In the warmer regions, cooling is commonly provided by evaporative cooling pads or misters in conjunction with circulating fans. In the Southeast, foggers are often used to cool brooding and grow-out broilers, while evaporative coolers are used for laying hens. Light traps can be a ventilation design complication for pullets because they can restrict airflow, especially when dirty. Research is needed to determine the optimum level of light blockage for poultry.

Poultry ventilation systems are similar to swine systems, although naturally ventilated systems usually do not have ridge vents and large openings are often provided on the endwalls as well as the sidewalls. Integrated controls are popular since management time is kept to a minimum.

Turkey. Turkey buildings are often naturally ventilated, or a combination of mechanical ventilation is used in winter and natural ventilation is used in warm weather. Curtain sidewall openings are common, although insulated doors are often used in cold climates. Circulation fans are commonly used for cooling. Computer controls may be used to adjust sidewall and ridge openings.

Cattle

Dairy cattle. Most dairy freestall buildings are naturally ventilated. Typically, there are no ceilings, with continuous ridge openings and minimal insulation. Dairy cattle are sensitive to heat and a summer slump of milk production is a major problem. Consequently, building designs are opening up the building to summer breezes as much as possible. Most have large curtain sidewall and even endwall openings for good summer cooling. Some buildings have curtains from floor to roof around the entire perimeter during cold weather, which is then removed for warm weather. Often there is some type of supplemental cooling, such as misters, sprayers, and/or circulating fans.

Calves are usually housed in individual calf hutches to control transfer of disease. Hutches are well insulated but have no supplemental heat other than maybe a heat lamp when needed. Calves are sometimes housed in large, open, well-ventilated buildings with individual pens. When calves are placed close together in heated buildings, disease is a major problem.

Beef cattle. Almost all beef cattle buildings are naturally ventilated, open-front buildings. Continuous open ridge vents and vent doors along the backwall are typical. Insulation, supplemental heating, or supplemental cooling are not used.

Effectiveness of Various Environmental Control Systems

According to one designer, mechanical ventilation systems are always more effective, but they are more expensive compared to natural ventilation systems. Another designer ranked the various ventilation systems from best to worst as follows: (1) negative pressure mechanical ventilation with gravity-controlled baffle diffusers, (2) combination of mechanical ventilation in winter and natural ventilation in summer, (3) negative pressure mechanical ventilation with manually controlled diffusers, and (4) natural ventilation systems.

Another expert stated that natural ventilation is more effective in the real world since it is simpler to manage. Several experts stated that negative pressure mechanical ventilation systems with automatic static pressure or gravity-controlled diffusers work the best for swine farrowing and nursery facilities. One expert stated that gravity-controlled diffusers do not adequately distribute and mix air.

Good air distribution with reduced drafts and low temperature fluctuations were cited as very important. Continuous slot diffusers with baffles were noted to have problems with poor materials and workmanship. If the baffles are not perfectly straight, there is an uneven distribution of air throughout the building. Diffusers that are fully assembled at the manufacturing plant and installed as a unit on site have some advantages over diffusers that are assembled on site. Diffusers that require constant manual adjustment are also a major problem since adjustments are rarely made on a timely basis. Static pressure controlled or counterweighted gravity diffusers were often cited as improving diffuser effectiveness. Using perimeter baffled slot diffusers in buildings wider than 40 ft (12.2 m) has not been effective. Another problem associated with mechanical ventilation systems is the noise generated by the fans. The noise is continuous and affects the building's occupants and neighbors.

Good fan design and selection is needed to provide the correct amount of dilution air that is especially critical in winter when the ventilation rate is at a minimum. Cold weather fans should be designed to deliver a consistent amount of air through a wide range of wind conditions. Fans should be located downwind relative to winter prevailing winds and should be protected from wind.

For any environmental control system to be effective, it has to be designed, constructed, and maintained properly. Probably the main reason for ineffective ventilation systems is a failure to do one of these well. Also, all environmental control system components need to be designed to work together as a system. It is too common to have systems with components obtained from different companies; thus, the components may not work together effectively.

For larger, more mature animals, properly designed and controlled natural ventilation systems were reported as effective in providing proper environment. For colder climates and more sensitive animals, a combined system with mechanical ventilation for cold weather and natural ventilation for warm weather works well. Automated vent opening size control is reported to be effective. Heat stress can be a problem on relatively calm days, and buildings near wind barriers or in low areas are especially a problem. Mixing or circulating fans are sometimes used to provide a higher velocity in the animal-occupied regions. More research is needed on these systems. Incorporating evaporative cooling with the circulation fans could possibly increase the benefit, as long as it does not create high humidities at high temperatures.

Some experts believe that tunnel ventilation is not the most effective method in providing a good environment. Others believe that it will be used by producers anyway to reduce costs; therefore, more research should be conducted to provide better design and management guidelines for tunnel ventilation. One expert stated that tunnel ventilation can be effective in alleviating heat stress but requires more management than other systems. For example, more precise staging control is needed to avoid cold stress in moderate temperatures.

According to many experts, no environmental control system can be effective with a poor waste management system. Long-term storage of manure in the building or poorly managed manure handling systems will reduce effectiveness of ventilation systems.

Most Common IAQ Problems in Animal Buildings

The most often mentioned IAQ problem was high concentration of particulate matter. Other problems mentioned include high concentrations of ammonia, hydrogen sulfide, other odorous compounds, moisture, molds, endotoxins, pathogens, and carbon monoxide. Health problems due to particulates in animal buildings are well documented for workers but not for animals. Excessive dust accumulation on heaters and electrical equipment in poultry buildings was also mentioned as a potential fire hazard.

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Existing Methods for Controlling IAQ Problems in Animal Buildings

The three basic IAQ control strategies can be helpful in reducing contaminant levels in the animal and worker zones, but usually a combination of one or more strategies is most effective in providing a good indoor environment.

Source Control

Most designers stated that the first defense against IAQ problems is to reduce contaminant production at the source, or to at least intercept and remove contaminants before they move into the animal and worker breathing zone. Animal feces and urine were cited as major sources of most contaminants. Feed systems, animals, and dried manure can also be major sources of contaminants, especially particulate matter.

Many experts strongly advise removing the manure from the building at frequent intervals, at least every three days. This removes the major source of many contaminants before they begin to decompose sufficiently to produce noxious, odorous gases. The trend is to store manure outside animal buildings. Slotted flooring also helps reduce contaminant production. Some experts recommend that dunging habits of swine be improved by proper design to reduce the amount of manure exposed to the air on solid surfaces. Pigs tend to sleep where they are most comfortable and dung elsewhere. Thus, anything that makes the animals comfortable on the solid floor will reduce a source of contaminant production. This may involve designing the ventilation system to direct cool air in winter toward the slotted area and then change to direct the cool, fresh air to the solid area in hot weather. The conditions at which there is a transition from the incoming air being uncomfortable to comfortable need more research but are known to vary considerably with pig size. Pen design can also have a major effect on pig dunging habits. Heated floors under manure-covered solid flooring can increase the release rate of contaminants. Covering manure as much as possible reduces the exposed surface area that is the source of contaminants to room air. A few inches of water covering was noted as being a major help.

For poultry buildings, the litter is a major source of particulates and ammonia; therefore, controlling humidity in the building to keep the litter moisture at appropriate levels can reduce contaminant production and release. Moisture condensing on cold surfaces of poultry buildings can wet the litter and lead to high ammonia generation. Utilizing improved litter materials that release fewer contaminants is being considered, but is more costly.

Adding chemicals to manure storage may have benefits in reducing contaminant production, but this method has been largely unproven. Some additives to swine feed have shown some promise in reducing contaminant release from manure, but more research is needed. Adding oils to feed is known to reduce dust levels in swine buildings by providing better adhesion of small particles to the feed. One expert reported significant particulate suppression with adding oil to the feed, while another reported only average effectiveness. Another method mentioned for reducing particulates is to keep the room clean, although one expert stated that this was only minimally effective. Maintaining relative humidity levels above 50% by proper ventilation management will also reduce particulate levels. Using covered feeders instead of dropping feed on the floor also reduces dust generation. Using all-in, all-out management for swine allows time in between animal groups to thoroughly clean the facility to reduce contaminant sources.

The source of carbon monoxide in animal housing is usually unvented heaters and catalytic heaters. Properly adjusted and clean heaters produce very little carbon monoxide; therefore, the best method of control is proper heater maintenance. Some experts recommend increasing the ventilation rate by 4 cfm (0.0019 m^3/s) per each 1000 Btu/h (0.3 kW) capacity of unvented heaters to dilute combustion gases.

Air Cleaning

Particulates are not easily removed by dilution (ventilation) processes, so other methods of removal are being tested. Filtration has not been found to be economical due to high particle loads in animal buildings. Electrostatic precipitators have been tried by several researchers with some success. New designs of electrostatic precipitators have particulate removal rates of 35% to 65%, and better systems are being developed. Improvements in animal health and performance have not been verified, but workers have reported better working conditions with electrostatic precipitators.

Some researchers have sprayed the room area with oils or water to suppress dust release. Some experts stated that this was only moderately effective, while others reported high particulate removal rates. There are still problems with the logistics and mechanics of oil spraying systems. Misters used for cooling in poultry buildings also precipitate dust and reduce dust release from litter by increasing litter moisture content.

Some experts believe that wet scrubbers show a lot of potential for reducing particulates and water-soluble gases from room air and from room exhaust. No effective methods are currently being used to scrub gases from the room air in animal buildings. Scrubbers are being utilized for various applications in industry, and it may be possible to transfer some of that technology to obtain a practical system for scrubbing air in animal rooms.

The viability of pathogens in the air is greatly reduced by maintaining relative humidities between 40% and 75%. The survivability of pathogens is greatly enhanced if they attach to aerosols or damp solid particulates; therefore, reducing particulate levels can also reduce the pathogen problems. Pathogens are probably a major source of health problems in animal buildings, and more research is needed in reducing their levels and viability.

Dilution Ventilation

Ventilation is seen as a very important method of removing air contaminants, especially gases, from air in animal housing. The ventilation system component cited as having the most problems is the air diffuser. Air diffusers need to be

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designed to provide better distribution of fresh air without drafts on animals and to be simple to operate. This is especially important during cold weather when ventilation rates are low. Some experts are recommending recirculation systems to obtain better mixing and to reduce thermal stratification of room air. However, care is needed with recirculation systems to avoid high air velocities in the animal region.

Increasing the ventilation rate and improving air distribution throughout the room is effective in reducing moisture and heat levels, somewhat effective in removing gases, and less effective in removing particulates. Increasing the ventilation rate can increase air velocity over the contaminant source surface, which can actually increase the release of the contaminant. Designing better ventilation systems that sweep the contaminants away from the occupied zones and out of the building rather than recirculating them would be very beneficial. Proper diffuser design was often cited as being important to provide uniform distribution of fresh air without creating drafts.

Many experts stated that poor ventilation design is a major problem leading to most of the worst cases of IAQ problems. Many of the current IAQ problems could be greatly reduced with proper application of good engineering principles to all animal facilities. Currently, many of the production animal facilities are designed by people with little knowledge of basic ventilation principles.

Most design experts strongly recommend removing at least some of the ventilation air from manure storage or gutter areas to intercept the gases before they move up to the animal/worker area. Most designs remove air from the manure areas at the cold weather rate continuously all year. One expert recommends moving all of the ventilation through the pit. It is important to remove air fairly uniformly from the manure storage/gutter area to intercept as many of the contaminants as possible. Moving this air through the slotted flooring into the manure area also dries manure on the slats to reduce contaminant production at that location.

EMERGING TECHNOLOGIES FOR CONTROL OF IAQ IN ANIMAL HOUSING

Current technologies are not properly utilized in production animal facilities. Far too many environmental control systems for animal facilities are designed by nonexperts. Even well-designed systems have problems when managed by people who do not understand how the system operates. Ventilation systems need to be designed so they are easy to operate and simple to understand. Utilizing heat exchangers, solar heat, or geothermal heat more often has the potential for improving IAQ by allowing a higher ventilation rate without substantially increasing energy cost. Heat exchangers need an air distribution duct to ensure proper distribution and mixing of fresh air.

Research is needed to improve the performance of air diffusers of mechanically ventilated buildings. Diffusers need more precise control and continuous, automatic adjustment to provide proper air distribution. Air diffuser types and locations also need more study to better distribute the air to the appropriate location without creating drafts on the animals in cool weather. In warm weather, the diffusers may need to direct high velocity air on the animals to provide sufficient cooling.

New types of ventilation systems that depend more on a sweeping action of air movement instead of a turbulent mixing concept need to be developed. Turbulent mixing of fresh air with room air attempts to control the contaminant level by dilution, which is not very effective, especially for particulates. The turbulence also creates drafts and can increase levels of contaminants by breaking down the boundary layer over sources. It also tends to spread contaminants throughout the air space, which enhances the transfer of disease organisms. A sweeping movement of air with low turbulence would be desirable to move contaminants from the sources and out of the building before they mix with air in the breathing zones. More affordable automatic air diffuser controls that will reduce the use of gravity and manually controlled diffusers will need to be developed. New diffuser designs should also consider obstructions to air movement in the room to avoid stagnant areas and disruption to airflow patterns.

Particulate matter is a larger problem in animal facilities than most people acknowledge. It aggravates lung tissue and carries pathogens and odors. High dust concentration was cited most often as being the major IAQ problem in animal facilities. Current technologies for controlling dust levels are inadequate. Electrostatic precipitator designs are being improved. Ozonation or wet scrubbing of air shows promise but needs a great deal of developmental work.

More precise environmental controller technology can improve IAQ. Its main advantage appears to be in providing better thermal environments by reducing temperature fluctuations. In general, automatic controls appear to provide more precise control of ventilation components than manual controls. The new controls may adjust the environmental control system diurnally since animals respond differently to thermal environment during day and night periods. Currently, computerized controls are too costly and too complicated for many facility operators.

Sensors need to be placed in locations that are representative of the environment being experienced by the animals and workers. Using only one sensor in a room is a potential hazard if that sensor should fail. New types of sensors will be developed to provide a wider range of input to integrated microprocessor-based controls. Parameters other than temperature, such as relative humidity, air velocity, gas levels, particulate levels, and animal behavior, will be considered more in the future. Sensor development will need research emphasis in the future to develop reliable units that can stay calibrated in harsh environments.

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RESEARCH AND DEVELOPMENT NEEDS

More research and development are needed to develop effective IAQ control strategies for production animal buildings. Specific research areas are summarized below.

1. Develop sensors and control devices that incorporate contaminant control technology into the environmental control system.
2. Develop standard air sampling and contaminant measurement protocols.
3. Develop a more fundamental understanding of the contaminant source and sink characteristics (e.g., type, strength, location) as affected by microenvironmental parameters (e.g., temperature, humidity, air velocity, and turbulence characteristics) and animal factors (levels of activity, etc.).
4. Develop better manure and litter management systems to reduce production of contaminants within animal buildings.
5. Evaluate effectiveness of feed and manure additives in reducing gas release rates from manure.
6. Develop improved ventilation diffuser designs and effective room air distributions systems.
7. Develop a more integrated system of contaminant and manure pit ventilation systems to intercept and exhaust gaseous contaminants before they mix in with the breathing air.
8. Evaluate the effectiveness of mixing and circulating fans in relieving heat stress and in improving room air distribution.
9. Develop more practical and economical air-cleaning strategies and devices, such as electrostatic precipitators and wet scrubbers, to remove particulates from room air economically.

SUMMARY AND CONCLUSIONS

A survey of experts on animal production housing facilities was conducted to determine current knowledge, identify potential indoor air quality measures, and define research and development needs. The following conclusions can be drawn from the study.

1. For larger, more mature animals, properly designed and controlled natural ventilation systems are effective in providing good environments. For colder climates and more sensitive animals, a combined system with mechanical ventilation for cold weather and natural ventilation for warm weather works well.
2. High concentration of particulate matter appears to be the most prevalent indoor air quality problem in animal housing facilities. Economical and practical methods for controlling particulate matter need to be developed.
3. The following strategies appear to be effective in controlling gaseous contaminants: (a) adequate ventilation rates, (b) manure removal within three days, (c) pit ventilation, (d) feed additives (i.e., oils or fats), (e) keeping the facilities clean, and (f) management strategies to reduce agitation of animals.
4. Most problems with poor indoor air quality are due to poor design and management of existing technologies.

To improve air quality in animal housing facilities, the following technologies should be developed and utilized: (1) proper design and operation of ventilation systems, (2) improved ventilation air diffusers and room air distribution systems, (3) economical and practical methods for removing particulates from the air (e.g., electrostatic precipitators, scrubbers), and (4) improved environmental control systems with better or multiple sensors.

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